Condenser Heat Recovery in Air Conditioning Systems

V. Hanus, J. Lebrun and V. Lemort

Thermodynamics Laboratory,
University of Liège
B4000 Liège, Belgium

ABSTRACT

This paper is based on the first Belgian case study developed in the frame of the IEA-ECBCS annex 48 project. It concerns an industrial building in which simultaneous cooling and heating demands subsist all along the year: boilers and chillers are working in parallel and nothing is currently done to recover the condensers heat.
In such existing building, one of the first energy retrofit to be considered consists in installing a heat pump between the chillers condensers and the hot water distribution, or in making the condensing temperature compatible with heating requirements.
The COP of this heat recovery process is expected to overpass 3.
Combined with the efficiency of a modern TGV power plant (~55%), this COP makes heat pumping using less than one half of the primary energy consumed by the best boiler available.
And the CO2 emission is reduced in proportion…

KEYWORDS

HVAC, Heat recovery, chillers, heat pumps

INTRODUCTION

Substituting a heat pump to a boiler may save more than 50 % of primary energy, if electricity is produced by a modern gas-steam power plant (and even more if a part of that electricity is produced from a renewable source).
One of the most attractive heat pump applications consists in recovering the heat rejected by the condenser of an existing chiller.
This is a matter studied in the frame of the so-called “annex 48: Heat pumping and reversible air conditioning” project of the “Energy conservation and community systems” implementing agreement of the International Energy Agency (IEA) [1].
Case studies are proposed and documented by all annex 48 participants.
One of the first case studies proposed by Belgium is presented hereafter [2].
It’s dealing with two possibilities of condenser heat recovery:
the “cascade” and the “single condenser” systems [3].

CASE STUDY: AN INDUSTRIAL BUILDING

The building, its energy production and HVAC equipment

The building:
The site is a test facility plant related to the automotive industry (Figure 1). It is located in the Grand Duchy of Luxembourg and has two functions: it accommodates research departments (about 500 engineers) as well as laboratories for engine, aerodynamic and air-conditioning testing.

The building was erected in the sixties to manufacture assembly lines. It was extended in the nineties to accommodate laboratories and research departments.The average yearly consumptions on site are:
170 000 MWh of electricity (cost: 800 000 €);
340 000 m3 of city water (cost: 100 000 €);
1 220 000 Nm3 of gas (cost: 250 000 €).

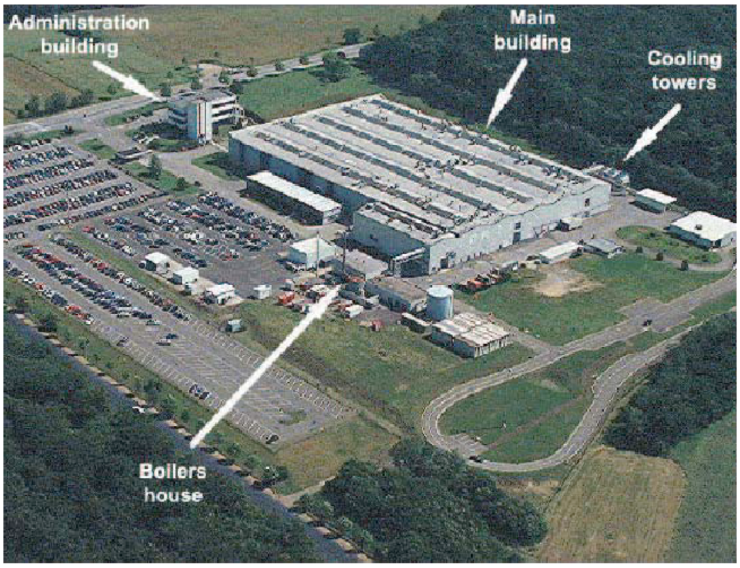

Figure 1: General view of the site

Its energy production equipment:

Four kinds of energy vectors are used to perform the air-conditioning: chilled water, cooling water, hot water and steam.
- The chilled water is produced by a set of five chillers with water-cooled condensers. The total capacity of this equipment is 3.5 MW.
- Four direct contact towers produce cooling water: the total nominal power is 9.5 MW for a total flow rate of 225 l/s. The design conditions are defined for water coming at 38 °C and leaving at 29 °C, with an air wet bulb temperature of 22 °C. Frequency inverters are used to control the fans of the towers.
- Two boilers are used to produce hot water. They are designed for a total power of 10 MW, with water temperature fixed at 120 and 130 °C in summer and winter periods respectively,

The HVAC equipment:

About 38 AHU are used. All together, they make:
700 000 m3/h and 500 000 m3/h of supply and exhaust airflow rates, 6.5 MW of pre-heating, 5.2 MW of cooling and 0.5 MW of post-heating.

Some of these AHU's are sized in such way that their heating coil may require a very high water temperature regime: 160/120°C.

The "cascade" system

It consists in adding heat pumps (also called "templifiers") between the cooling and heating circuits.

The possibilities offered by this system have to be evaluated by looking at:
- the technical feasibility;
- the money savings;
- the CO2 emission reduction.

Break-even point COP for money savings:
Hot water is nowadays produced by natural gas boilers.
Its cost is estimated to 35 €/MWh.

The production cost of the cascade system would include three main components:
- the electricity costs (average price: 60 €/MWh);
- the maintenance costs (estimated to 9.8 k€ /year for 3 templifiers of 1.2 MW);
- the depreciation costs (estimated to 76 k€ per heat pump of 1.2 MW).

A marginal saving (3.6 €/MWh) has also to be taken into account: the energy recovered doesn't need to be dissipated by the cooling towers.

The break-even point COP of the heat pumps can be calculated as follows:

$$COP = \frac{Price_{electricity} + Saving_{cooling\ water}}{\frac{Price_{gas}}{LHV_{gas} \cdot \eta_{boilers}} + Saving_{cooling\ water} - Cost_{maintenance} - Cost_{depreciation}}$$

Of course, this calculation is very affected by heat pump sizing and by the amount of energy recoverable on a given time period: higher is the investment and higher is the break-even point COP.

With the investment actually considered (for the 3 templifiers of 1.2 MW), the break-even point COP would be of 2.2. This should not be a problem…

Break-even point COP for a reduction of CO2 emission
This COP can be defined by considering the CO2 emitted by the heating boilers and by the electrical power plants (about 319kg/MWh in Benelux).
Not only the heat pumps compressors, but also all "auxiliary" electrical consumers (as boilers and cooling towers fans) are taken into account in this calculation.

In the present case, the break-even point COP is of about 1.1, i.e. very much below its economical value.

Correlation between consumption and possible production
Weekly heating and cooling consumptions have been recorded and analyzed in such a way to identify their mutual correlations. Such analysis should still be extended on shorter (day and hour) time basis, but it gives a first estimate of the recovery potential.
It appears that about 2 and 2.5 to 3.5 GWh are recoverable in summer and winter seasons respectively. The winter variation is related to the heat pump COP.
The heat recovery potential can be converted into money savings and reduction of CO_2 emission. Both results are very sensitive to the COP when this one is lower than 3. But higher COP are very probably achievable…

Temperature reduction of hot water distribution circuit

Some of the AHU heating coil have been sized for very high water temperature (160/120°C). By simulation on a reference year, it's possible to calculate the actual amount of heat recovered by these coils, as function of the water temperature.
A results synthesis is given in Figure 2.

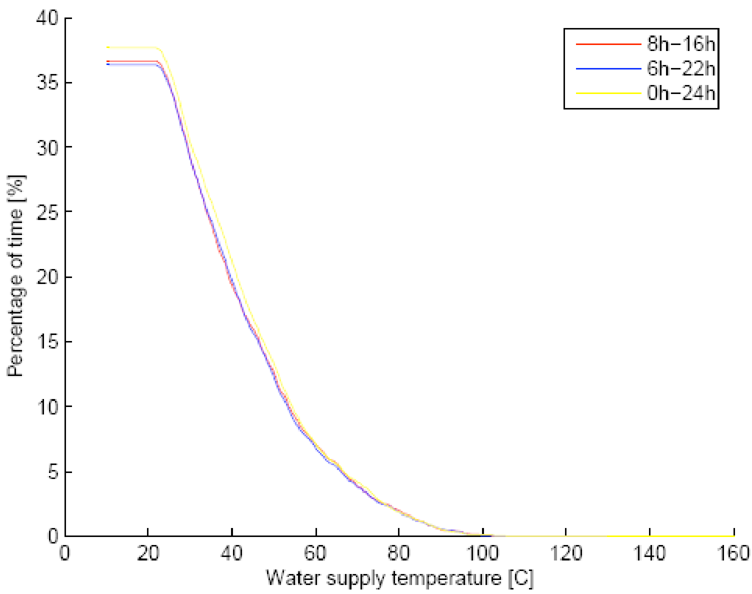

Figure 2: Percentage of working time when conditions are not reached

It appears that lowering the water temperature under 60°C would increase rapidly the time fraction during which the required conditions would not be satisfied. But this is not crucial: existing templifiers are able to reach 80°C if required…

The "single condenser" system

Raising the temperature of existing condensers is more attractive than adding heat pumps in the existing system.
But a compromise must be found between heat distribution and chillers tolerances.

Temperature reduction of some heat users
An alternative to the problematic temperature lowering in the whole hot water distribution system consists in re-sizing the heating coils of a selected number of AHU's. Such energy retrofit is less expensive than the use of templifiers. It consists in increasing the number of rows of each coil, or in installing several coils in series.
This increases the airside pressure drops. A water flow rate increase is also welcome in order to reduce the supply-exhaust temperature difference. The consequences are: bigger fans and pumps and higher "auxiliary" consumptions.
In the case considered, lowering the hot water temperature below 30°C would be meaningless.
For a satisfactory economical optimization, caution should be paid to:
"water" costs (loss of chillers performances – savings thanks to reduced use of cooling towers), fan running costs, pump running costs and investment costs (new heat exchangers, new distribution circuit, new pumps, etc.).

Performance loss of the chillers

The penalty associated to higher of condensation temperature must be carefully evaluated by simulation.
An example of modeling result is given in Figure 3. The simulation model has been tuned on the basis of manufacturer data.

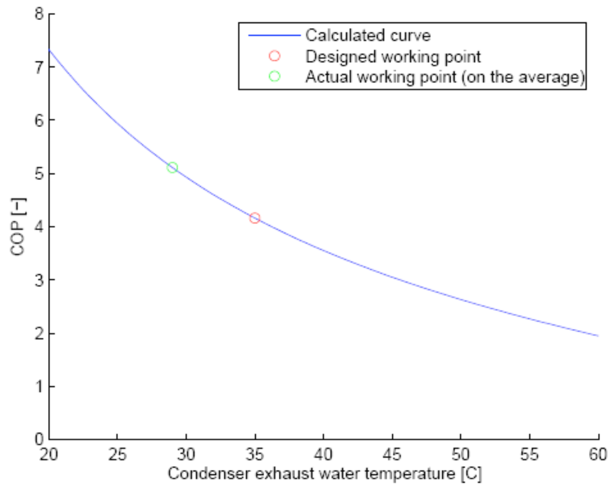

Figure 3: Performance loss of the chiller Nr 1

Fictitious heat pump COP

For easy comparison with the "cascade" system, these results can also be expressed in terms of COP of a fictitious heat pump (COP_{hp}) performing the same task. This COP can be expressed itself as function of the "actual" and "reference" COP's of the chiller (COPch and COPref, respectively):

$$COP_{hp} = \frac{1}{\frac{1}{COP_{ch}} - \frac{1}{COP_{ref}}} + \frac{1}{1 - \frac{COP_{ch}}{COP_{ref}}}$$

For the chiller considered, the evolution of this “marginal” COP is given in Figure 4.

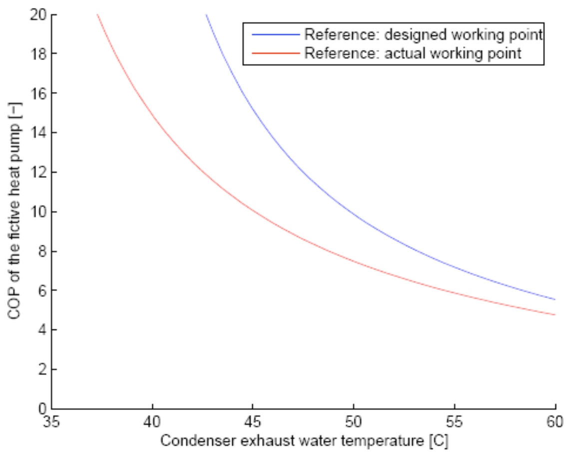

Figure 4: Fictitious heat pump COP

The single condenser solution appears here as very attractive: its heat pumping COP is far above the break even point COP’s already identified. A key issue is the choice of the heat “users”, in order to extend, as much as possible, the heat recovery time period. The best heat “users” are here the post-heating coils, because they are used in both winter and summer time…

CONCLUSIONS

Competitive performances can be reached with both solutions considered and with the today technology.

A cascade system can supply the site in heat during all the summer period, but only partially during winter. In the studied case, the COP range is well above 3.

The single condenser system has here higher performances than the cascade.

A temperature lowering for some heat users is preferable to the temperature reduction in the whole distribution circuit:

The choice of the heat “users” is crucial. Post-heating coils are here “ideal users”.

References

[1] IEA ECBCS Annex 48: “Heat Pumping and Reversible Air Conditioning”
[2] V. Hanus: “Condenser Heat Recovery in an Air-Conditioning Plant”. Finishing school work.Faculty of Applied Science (ULg), June 2005.
[3] Dorgan Chad B. et alii: “ Chiller Heat Recovery Application Guide” ASHRAE project 892 Final Report 1999